THE WEATHER AND CIRCULATION OF SEPTEMBER 1956[1]

Including a Discussion of Hurricane Flossy and September's Typhoon Tracks

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1. THE GENERAL CIRCULATION

The 700-mb. circulation of September 1956 was characterized by above normal westerlies at middle latitudes, near normal westerlies to the north, and a stronger and more extensive than normal easterly belt in the Tropics. Figure 1, the latitudinal wind profile at 700 mb. (averaged over 360°), shows no displacement of the westerly maximum from normal. It does, however, suggest strong anticyclonic shear south of the stronger than normal peak values since the westerlies fell to below normal strength at 37.5° N. and the easterlies (at 700 mb.) extended northward to about 28° N. The net effect was an intensification and latitudinal contraction of the subtropical ridge axis, with a mean northward displacement of the ridge axis.

Figure 2, the mean 700-mb. contours and height departures from normal for September, delineates the perturbations associated with the hemispheric wind profile of figure 1. Three major "full"-latitude troughs can be seen, over eastern North America, central Russia, and the central Pacific. The strongest of these was the Russian trough with heights almost 400 ft. below normal. In addition there were 3 secondary troughs: in the eastern Atlantic, eastern Asia, and eastern Pacific. The latter of these existed on the southern periphery of the 700-mb. westerly belt and was directly involved in the zonal westerlies on only a transitory basis. On some occasions it was completely cut off from westerly control.

In many respects this pattern was quite similar to that of August 1956 [1] with, however, many of the features showing westward displacement. A notable exception to this general retrogression was the shear of the eastern Atlantic trough of August as the higher-latitude portion proceeded eastward and deepened in Russia (cf. above and fig. 2). The lower-latitude portion of the trough remained in a position quite similar to that of August and continued the anomalous cyclonic activity at middle latitudes of the eastern Atlantic. In possible connection with this situation, it is of interest to note that the *S. S. Roma* reported a small ice floe near the Azores (41°30′ N., 29° 00′ W.) on September 12—an unusual happening in recent years.

[1] See Charts I-XVII following p. 352 for analyzed climatological data for the month.

2. TEMPERATURES IN THE UNITED STATES

The pattern of a ridge over the western United States and a trough in the East is a common one in summer and fall months. During September an intensified subtropical ridge axis was displaced northward in the West and a stronger than normal trough dominated in the East. These may be readily related to the temperature and precipitation anomalies, particularly because the circulation features were unusually persistent throughout the month.

The observed temperature regime for September (Chart I, A and B) showed that above normal temperatures prevailed over much of the West under above normal heights and anticyclonic circulation at 700 mb. Considerable areas of the Southwest averaged 4° to 6° F. above normal. Numerous daily and late-season maximum temperature records were broken. San Diego had the highest average maximum temperature for any month of record, Burbank had its warmest and sunniest September, and Los Angeles and Tucson had their second warmest Septembers of record.

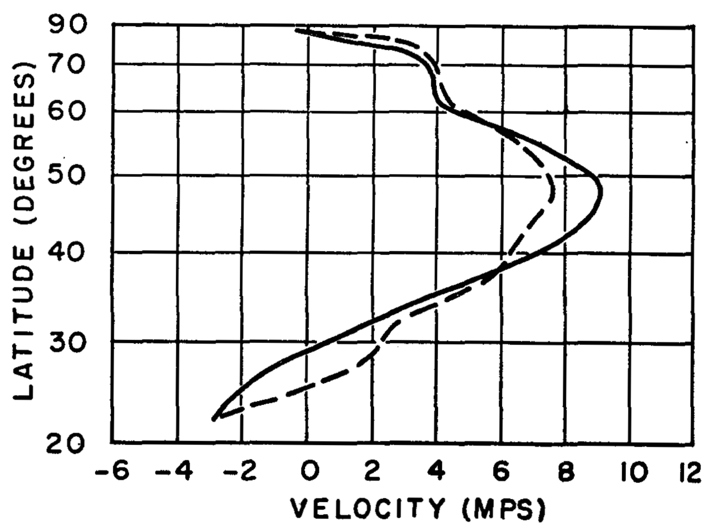


FIGURE 1.—Mean 700-mb. zonal wind-speed profile in meters per second for the Northern Hemisphere (360°) for September 1956 (solid curve) with normal September curve dashed. Note peak westerlies were stronger than normal but not displaced from normal latitude of maximum, although easterlies (negative values) extended farther north than normal.

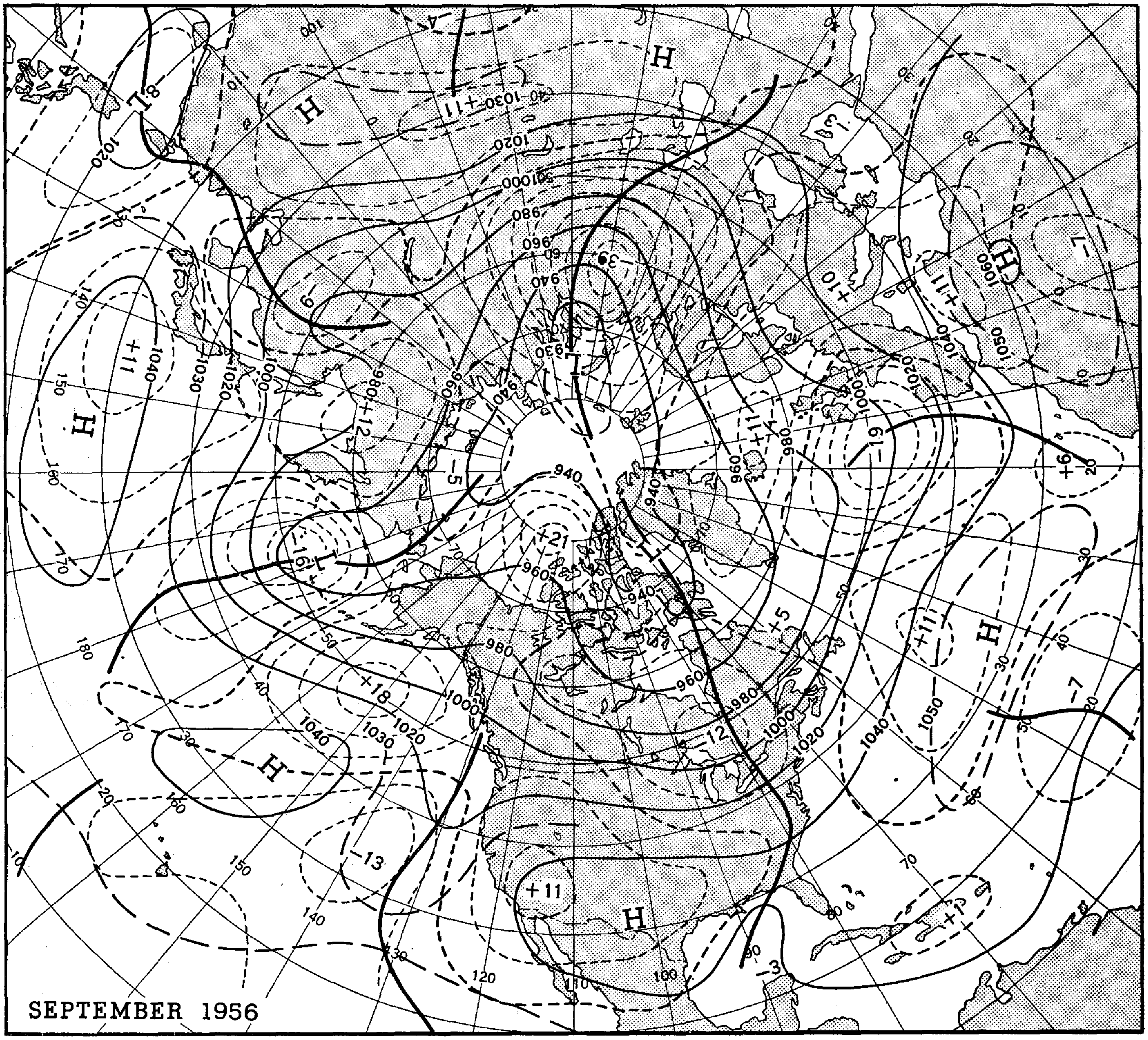


FIGURE 2.—Mean 700-mb. height contours and departures from normal (both in tens of feet) for September 1956. Regional features of note include: strong ridge in western North America, trough in eastern North America, pronounced middle-latitude trough activity (similar to August 1956) in eastern Atlantic, greatest departures (−390 ft.) in Russian trough.

Contrariwise, the East was under the influence of cooler than normal Canadian air. Behind the cyclones (Chart X) passing eastward through southern Canada or northeastward through the Great Lakes, outbreaks of cold Canadian air (Chart IX) swept southeastward into the mean trough. Temperatures averaged 6° F. below normal in parts of Pennsylvania and Ohio and generally below normal everywhere east of the Mississippi Valley. In northern States the departures were relatively extreme as Caribou and Portland, Maine reported their second coldest September; Albany, N. Y., the coldest September in 120 years; Scranton, Pa., its coldest on record, and Boston, Mass., its coldest since 1917.

Scranton, Pa., and Buffalo, N. Y., had their earliest snows on record, and Sault Ste. Marie, Mich., its greatest September snowfall (2.7 in.). One may evidently conclude that the pronounced and persistent ridge-trough configuration combined with colder than normal conditions over the Canadian source region [3] to effect marked deviations from average September weather.

A comparison of the monthly temperatures for August [1] with those for September indicates that a considerable change in regime occurred. Only 21 percent of the country remained unchanged in temperature class and only 54 percent remained within one temperature class.[2] This was in contrast with the strong persistence which operated from July to August (85 percent within one-class change). These changes can be associated with retrogression of the United States trough-ridge system and the increased number and enhanced cooling effectiveness of Canadian Highs affecting the eastern United States.

3. THE DROUGHT

Despite these well-defined characteristics of the temperature pattern, more critical attention was devoted to the precipitation distribution. From Texas northward into eastern Nebraska and westward into the Far Southwest areas of extreme drought have been common for some time. September brought little or no relief to these critical areas. Charts II and III show just how inadequate was the precipitation of September in the area where it was most needed. Over much of the drought area the total rainfall was less than half an inch.

The deficit was part of a long-sustained regime. Figure 3, showing the 7-week precipitation totals ending October 7, includes precipitation data both before and after September. It maintains the general September regime with but minor exceptions. It does not, however, do full justice to the calamity. Some areas of Texas and the Southwest are experiencing drought conditions comparable to the worst in their histories [13]. Pastures and unirrigated crops have, in many instances, been almost a total loss. Forced selling of livestock and importation of government-subsidized feed have become common.

The pattern of Mid-Western drought has been noted frequently in preceding articles in this series. Namias [12] and Klein [7] have pointed up the characteristic summer and fall circulation patterns associated with drought in the United States. A number of the summer features, or their counterparts, can be found in figure 2. However, the prerequisite ridge-trough system over the United States was more like the fall pattern of drought exemplified by October 1952 [18] or September 1953 [7]. The latter month was similar to this September in a number of respects in addition to the drought regime (e. g., see the date and path of hurricane Florence) but, curiously enough, was quite dissimilar over the eastern Pacific. This may, as Namias [12] has indicated, further substantiate the influence of the Atlantic sector on North American circulations.

From a longer-range point of view, the mid-continent drought area was displaced southward relative to the drought area of the "thirties" when it extended to the Canadian border. Although a completely satisfactory and objective drought index has not yet been developed,

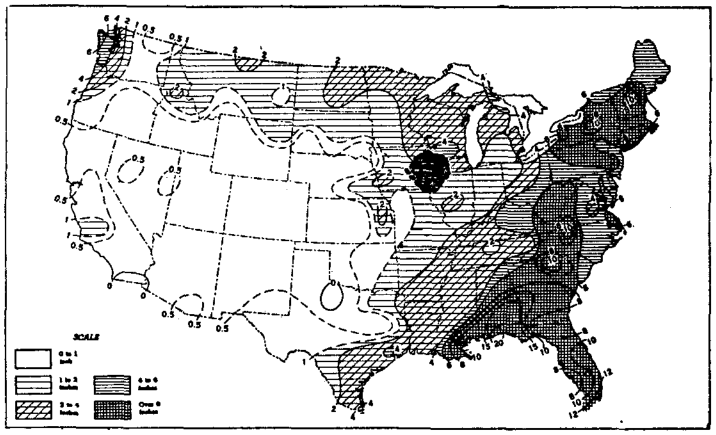


FIGURE 3.—Total precipitation (inches) for 7 weeks ending midnight l. s. t. October 7, 1956. Less than one-half inch of precipitation fell over most of the drought areas of Texas, Central Plains, and southern Rocky Mountain States. (From *Weekly Weather and Crop Bulletin, National Summary*, vol. XLIII, No. 41, October 8, 1956.)

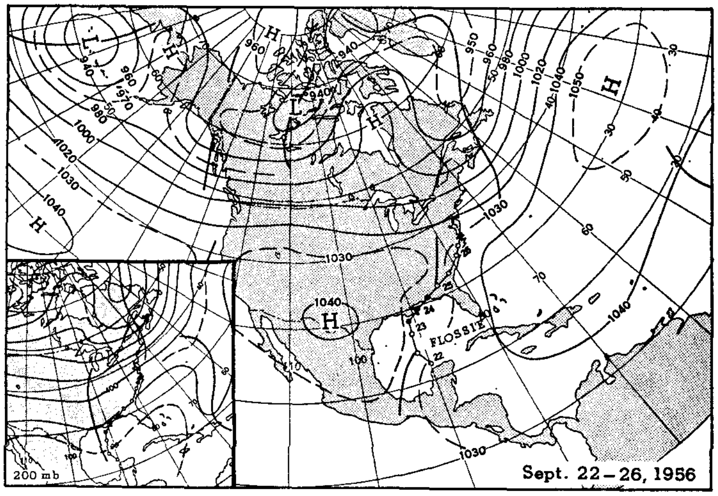


FIGURE 4.—Path of hurricane Flossy (12-hour positions) relative to 5-day mean circulations at 700 mb. (200-ft. contours) and 200 mb. (inset, 400-ft. contours) for September 22–26, 1956. Dates indicate 7 a. m. EST position; solid circles indicate full hurricane intensity. Note eastward tracking relative to 200-mb. flow.

there is general agreement that current conditions in the drought area defined above are the culmination of recurrent moisture deficiencies, particularly during the growing season, over a number of years. Namias [12] has treated summer drought patterns of 1952–54. Palmer [13] compared historic droughts with the current one in western Kansas by means of an experimental index and in [14] shows the extent and severity of drought conditions for the period 1954–56. Thus, over much of this area, the current drought can be traced back through four summers and current hardships are the culmination of a prolonged pattern of moisture deficiency. The basic reasons for such phenomena are still unexplained. However, with the growth of knowledge in the physical sciences, new concentration on this specific problem may lead to a general solution which will permit the forecasting of these regimes.

[2] Monthly temperature classes are defined with reference to the monthly variability and normal temperature for each station. Limiting departures are determined from past records so that the classes below, near, and above normal each occur ¼ of the time, while much below and much above occur ⅛ of the time.

Areas receiving appreciable precipitation (cf. Charts II and III) were restricted to the extreme Northwest, where the mean trough effected a limited rainfall; the northern Great Lakes, which was influenced by the passage of migratory cyclones into the nearby trough; and the area from the western Appalachians eastward. The rainfall in the northernmost portion of this latter area was associated with typical cyclonic activity associated with the mean trough. That in the southern portion was due in large part to hurricane Flossy, the only hurricane which entered the United States this season.

4. HURRICANE FLOSSY

Hurricane Flossy first became a closed circulation over the Yucatan peninsula on September 21 [16]. Its formation might be profitably investigated in detail in a later study. In gross aspect initial deepening might be related to a circulation sequence proposed by Riehl [15]. In this sequence an intrusion of polar westerlies or northwesterlies (at high levels) into lower latitudes provides the divergence mechanism which deepens a preexisting disturbance, in this case, a westward-moving easterly wave. The closed low center, once formed over Yucatan, moved north-northwestward through the Gulf of Mexico and reached hurricane intensity on the 23d, southwest of Burrwood, La. Flossy's track, including its subsequent northeastward motion, together with the attendant 5-day mean circulation at 700 and 200 mb., is shown in figure 4. The sheared trough over eastern North America (both levels) for the period September 22–26 had been a continuous trough during the preceding period, September 18–22. Northwesterlies to the rear of the lower-latitude trough presumably supplied the necessary divergence mechanism [15]. At lower levels (700 mb.) one might associate the injection of cyclonic vorticity from the westerlies into lower latitudes with the preexisting Low sought by Bergeron [2]; i. e., the mechanism for organizing the convective circulations as described by Namias [10]. It seems logical to assume that since the trough shear was not followed by rapid anticyclogenesis at higher levels over central United States latitudes, the continued presence of westerlies aloft influenced the strong eastward component of motion which prevailed as the storm emerged from the Gulf.

At the 700-mb. level the direct trace of the storm in the contour field was clearly evident, but reason for the strong eastward steering could be found in the westerlies at 200 mb. (fig. 4, inset). The track could also be related to the monthly mean 700-mb. pattern (fig. 2).

In typical fashion, Flossy lost its hurricane winds shortly after moving inland and became extratropical in character at a relatively early stage over Georgia.[3] Highest winds were estimated 90 to 110 m. p. h. at Burrwood, La. and 64 m. p. h. at Pensacola, Fla., decreasing farther northward. Motion was quite slow, particularly after the storm acquired extratropical form. This deceleration was, in part at least, associated with southeastward motion of the ridge over Canada (fig. 4) and subsequent blocking of the storm. As a result of the slow motion, precipitation was fairly heavy over wide areas of the Southeast. Total storm rainfall amounted to 7.05 in. at Burrwood and 10.69 in. at Pensacola. It decreased farther northward to 7.09 in. at Mobile, Ala., 4.4 in. at Columbia, S. C., 3.42 in. at Hatteras, N. C., and 1.50 in. at Richmond, Va. A number of tornadoes were reported in connection with the storm. Total damage, much of it due to flooding and wind-driven waves at coastal installations, was estimated at $12 million. Apart from its violent aspects, Flossy greatly relieved the droughty conditions which had prevailed in northern Florida, Georgia, and the Carolinas.

5. TYPHOONS AND TROPICAL STORMS RELATED TO MEAN CIRCULATION

If one assumes that strong, deep (latitudinally and vertically), subtropical easterlies often accompany hurricane development, then this past September should have been a prolific hurricane spawner. Both at sea level and 700 mb. (figs. 1 and 2), and presumably, at 500 mb., the Atlantic easterlies were stronger than normal. In all, four tropical storms were tracked in the Gulf-Atlantic area during September. This was greater than the usual frequency of occurrence. Only one, Flossy, reached hurricane strength and at least one (Ethel) lacked rigorous substantiating data of sustained existence over considerable time (see Chart X). Apparently the gross pattern was favorable to initiation, but the sensitive conditions necessary for full development were not concurrently at hand. It seems highly likely that the mean circulation was unfavorable for hurricane incidence over the New England States since the strong westerlies almost precluded the possibility of an Atlantic hurricane reaching that area. Although figure 2 shows several features in common with the pattern of height anomalies associated with "maximum hurricane threat" (to New England) found by Namias [11], it notably lacks the key positive height anomaly over central Canada and is quite dissimilar over the Pacific and eastern Atlantic. It is intriguing that the only hurricane type (Gulf) which might have had the capability of reaching the northeastern seaboard almost did just that, as Flossy managed to produce some gusty winds and moderate rain as far north as southern New England. This may be compared to hurricane Betsy of August 1956 [1].

In contrast to the dearth of full hurricane activity in the Caribbean was the series of typhoons which occupied the western Pacific during September. Including typhoon Dinah, in progress as the month began, and the short-lived Ivy, there were 6 typhoons of full hurricane intensity in September—a significant increase over the 3 or 4 storms which normally approach typhoon intensity during this month [4]. Half of these typhoons did not recurve but crossed the coastline into the continent of

[3] For a detailed discussion of this transition see adjacent article by Richter and DiLoreto

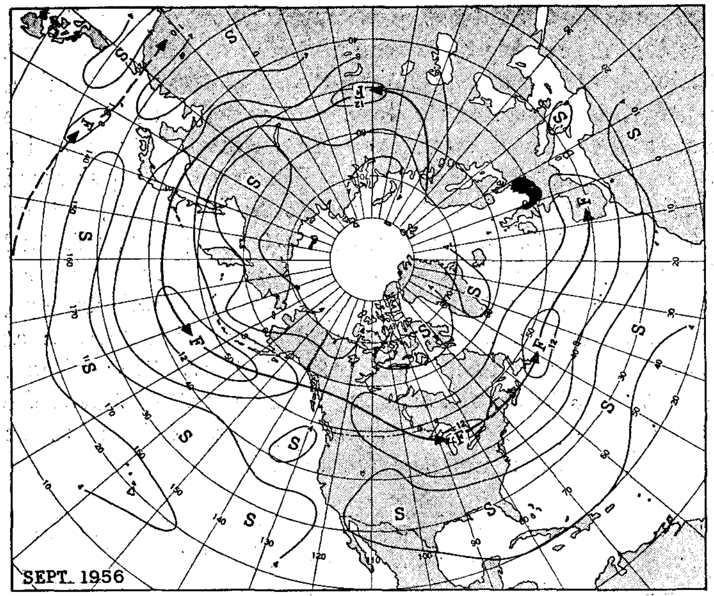


FIGURE 5.—Mean 700-mb. isotachs (labeled in meters per second) for September 1956. Axes of westerly maxima indicated by solid, easterly by dashed, arrows. 700-mb. easterlies were quite strong in tropical western Pacific but data coverage was not adequate to show strength and location of Atlantic easterly maximum.

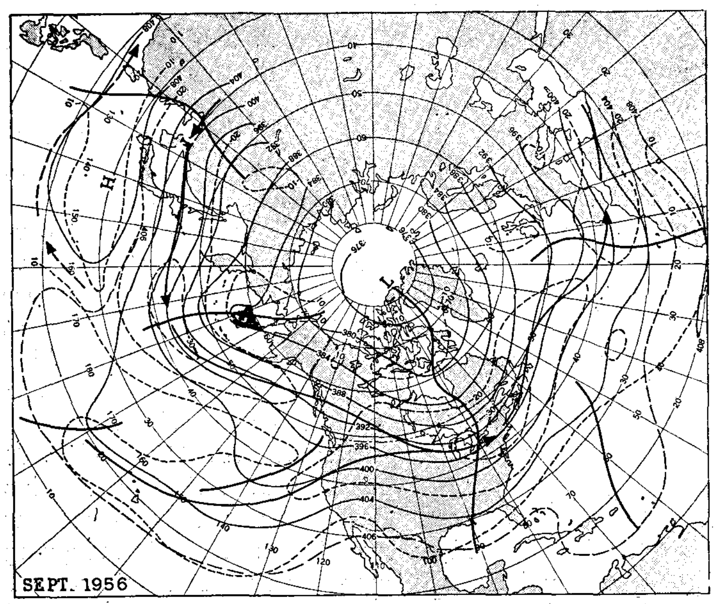


FIGURE 6.—Mean 200-mb. contours (in hundreds of feet) and isotachs (in meters per second) for September 1956. Solid arrows show westerly jet was fairly far south and strong over eastern North America. Easterly maximum (dashed) extended quite strongly to 200 mb. in western Pacific.

Asia. This percentage was not unusual, but the latitudes at which the storms entered the China coast were farther north than usual; i. e., Formosa rather than Hainan [4].

Mean conditions over the western Pacific were, a priori, (as in the Atlantic) favorable to tropical storm development. At 700 mb. (fig. 5) the easterlies were stronger than normal, as was the subtropical ridge. The latter was also farther north as well as stronger than normal. Both of these factors may be related to the higher frequency of unrecurved storms at Formosa and the westward displacement (from normal) of the locus of typhoon activity. The mean 200-mb. pattern, figure 6, shows the subtropical ridge extending east-northeastward from just north of Formosa. An east wind maximum was observed (dashed arrow, fig. 6) south of the ridge, a regime quite different from that which prevailed over the western Atlantic.

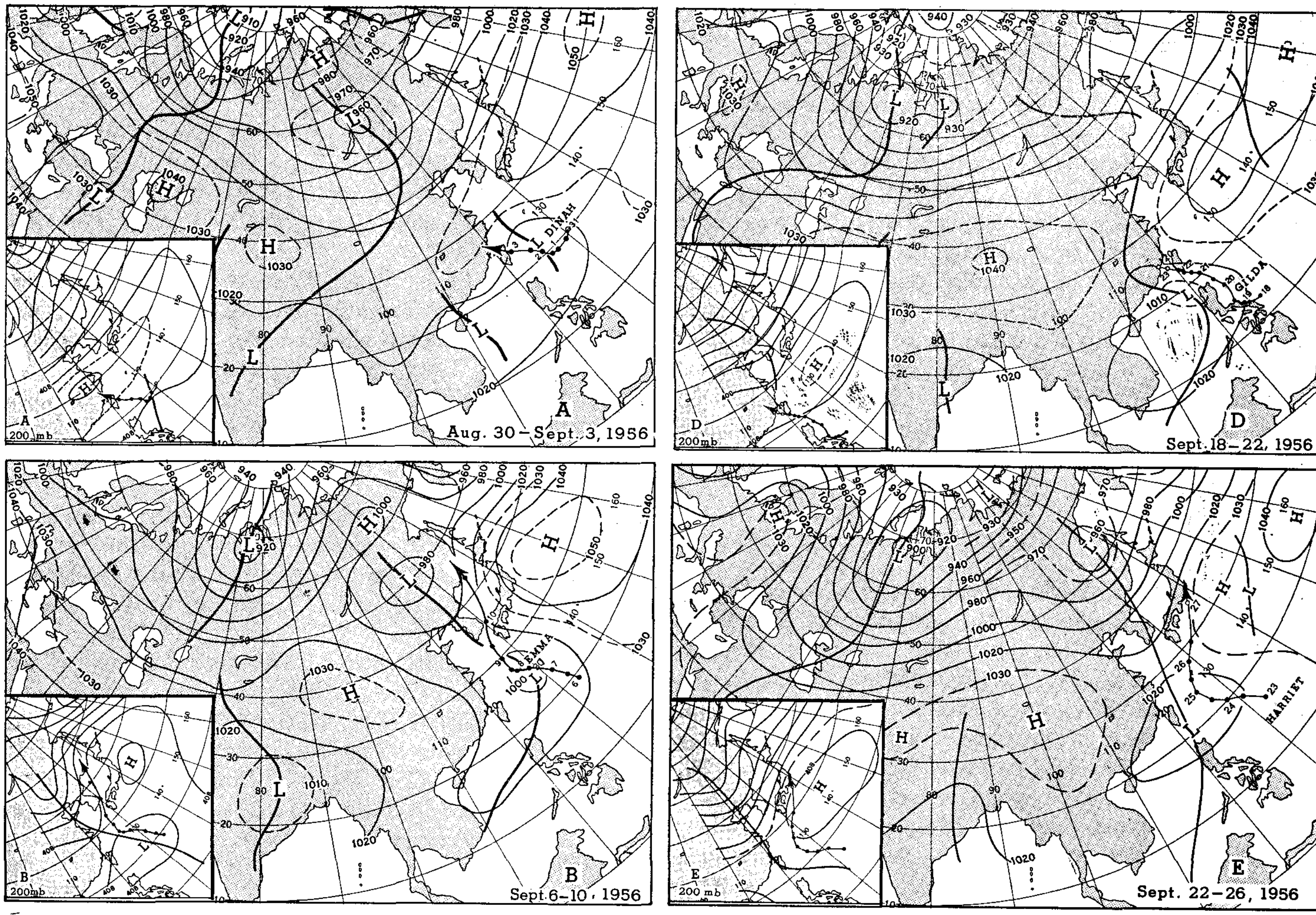
Figure 7 shows the tracks of the 5 major typhoons of September in chronological order, together with the appropriate 5-day mean 700-mb. and local 200-mb. circulation patterns. In general, one might expect this type of activity, given the monthly circulations (figs. 2, 6). Comparisons may be made with similar data relating tropical storms to mean circulation [1, 5, 7, 10, 11, 19]. However, it should be of some further interest to examine the differences in circulation patterns attending recurvature as opposed to the cases of no recurvature. Since mean maps over Asia are not available at 200 mb., most of the circulation characteristics must be discussed in terms of the 700-mb. features. In general, the main westerly circulation features are similar, but by no means identical at the two levels.

A. TYPHOONS NOT UNDERGOING RECURVATURE

Typhoon Dinah, figure 7A, roughly illustrates the classical pattern in which recurvature is improbable. The long-wave trough over Siberia was almost a half wavelength upstream from the tropical cyclonic activity. The resulting difference in phase between high- and low-latitude systems operated to strengthen the ridge north of the typhoon and to prevent recurvature before the storm was driven ashore and dissipated. At 200 mb. the strong zonal ridge with upper-level easterlies to its south exerted a similar influence.

Typhoon Freda, figure 7C, followed a path almost identical to that of Dinah. However, it is quite evident that there was a westerly trough to the north of the tropical disturbance and the main question might be: why did the typhoon not recurve? This question is particularly apt in view of the high latitude of the storm path. The answer appears to be in the flat, fast, westerly flow across Siberia which occurred downstream from a confluence regime over European Russia. The subtropical ridge is maintained reasonably well to the south of such flows and was strongly in evidence at the 200-mb. level (fig. 7C, inset). In the last analysis, the breaking of the subtropical ridge axis in borderline situations may depend on the timing of the westerly trough to the north relative to the normal approach of the tropical storm to the ridge axis. In any case, the effectiveness of a given trough in breaking the subtropical ridge is determined by the amplitude and location of the upstream trough-ridge system [6, 8, 9, 17].

The general situation was very similar for typhoon



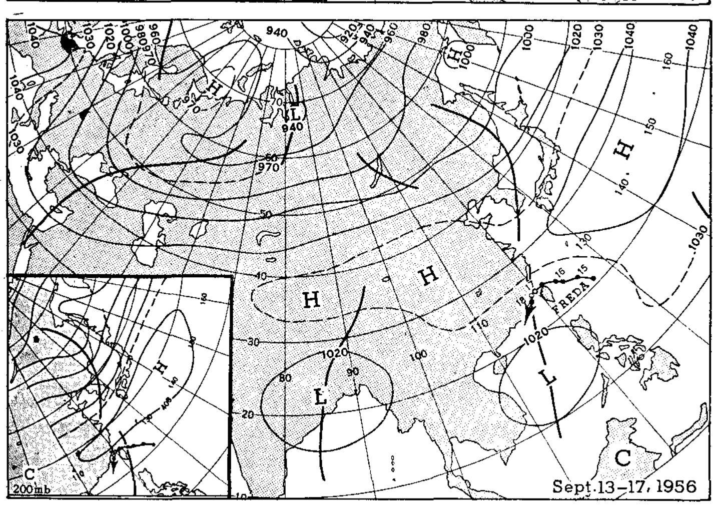


FIGURE 7.—Typhoon trajectories (slightly smoothed, from reconnaissance reports) relative to 5-day mean circulation patterns at 700 mb. (200-ft. contours) and 200 mb. (inset, 400-ft. contours). Plots show 12-hour positions with dates at the 0000 GMT position. Closed circles indicate full hurricane intensity (winds ≥ 75 m. p. h.), open circles, tropical storm of lesser strength. Low-amplitude waves to the north in the westerlies and strong subtropical ridges (note 200-mb. insets) prevented recurvature of typhoons Dinah (A), Freda (C) and Gilda (D). Typhoons Emma (B) and Harriet (E) both recurved through well-defined breaks in subtropical ridge with high-amplitude waves in westerlies common to both patterns. Typhoon Ivy (in the trough at 25° N., 145° E. on figure 7E) had a short life (26th–27th) and preceded Harriet into the westerlies.

Gilda, figure 7D, which originated some 8° farther south than Freda. It, similarly, could not break through the subtropical ridge primarily because of the strength of the ridge axis (note fig. 7D, inset) and the low amplitude of the westerly perturbations to the north.

B. RECURVING TYPHOONS

The foregoing may be contrasted with the typhoons which recurved: Emma, figure 7B, and Harriet, figure 7E. In these cases, at both 700 and 200 mb., wave amplitudes were greater both locally and upstream. The 200-mb. ridge was weakened or completely broken through as 200-mb. steering appeared operative. From the data currently available, it appears that the 200-mb. ridge line gave better indication of both the break-through and the latitude of recurvature than did the 700-mb. level, which reflected quite strongly the storm circulation itself. While both Emma and Harriet struck Okinawa, the destruction accompanying Emma, one of the big Pacific typhoons, was much the greater (estimated at some $20 million). In addition, Emma was responsible for further damage in Korea and Kyushu, and the loss of a weather reconnaissance plane over the sea of Japan.

In summation, the monthly patterns were representative of the general location and type of typhoon activity, but the recurvature of a particular perturbation was more closely related to the general amplitude and phase of the westerly systems and, in borderline cases, to the timing of the westerly troughs relative to the typhoon approach to the ridge. Thus while the mean monthly circulation may generally delineate the locus of tropical storm activity for that same period, the recurvature of particular storms depends on the amplitude and position of the trough-ridge features contemporaneous with the storm and relevant to the monthly circulation state.

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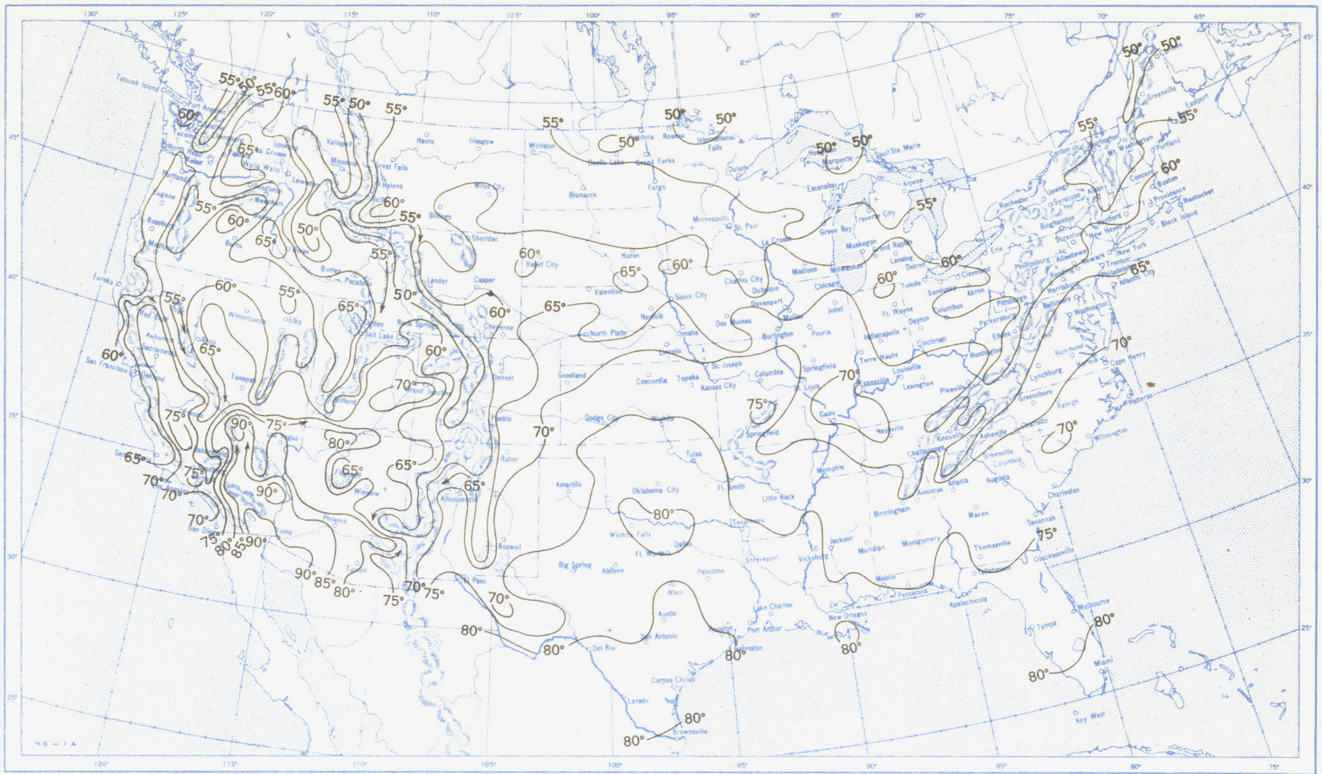
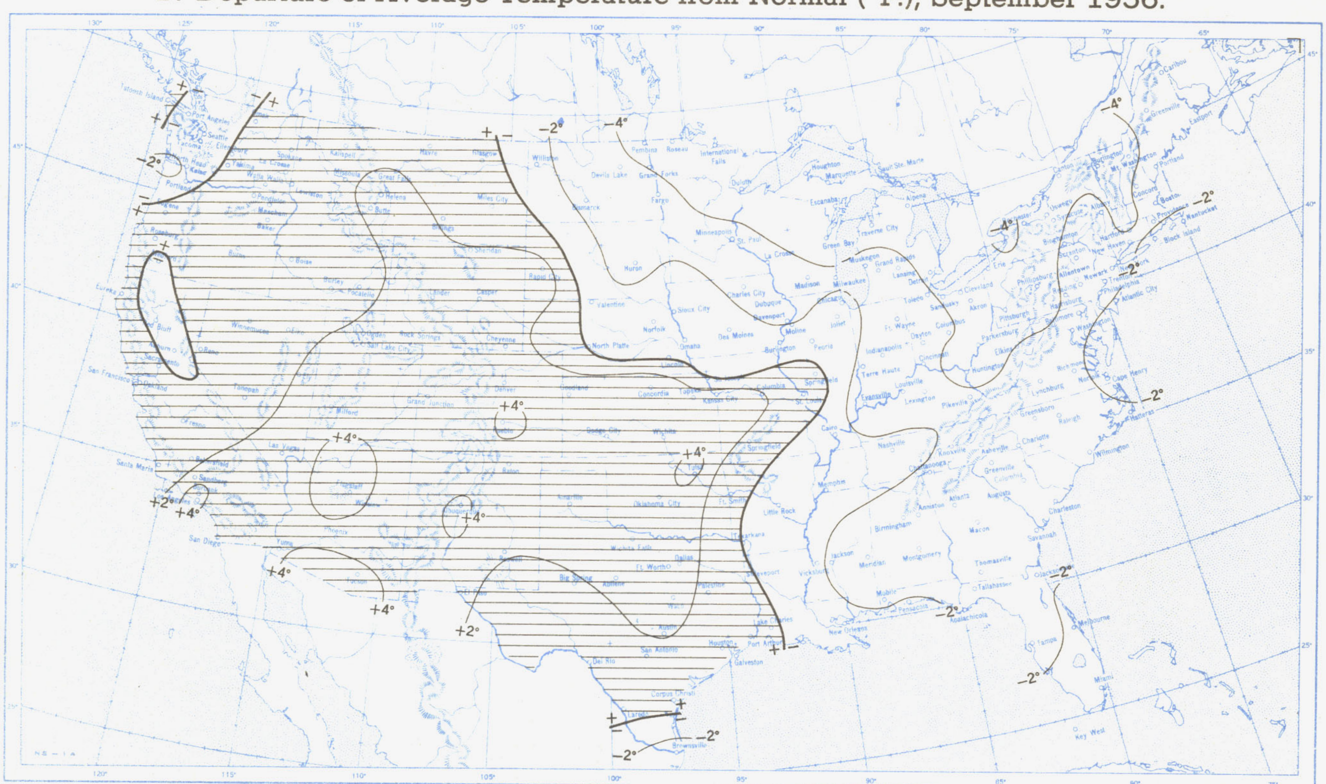
Chart I. A. Average Temperature (°F.) at Surface, September 1956.



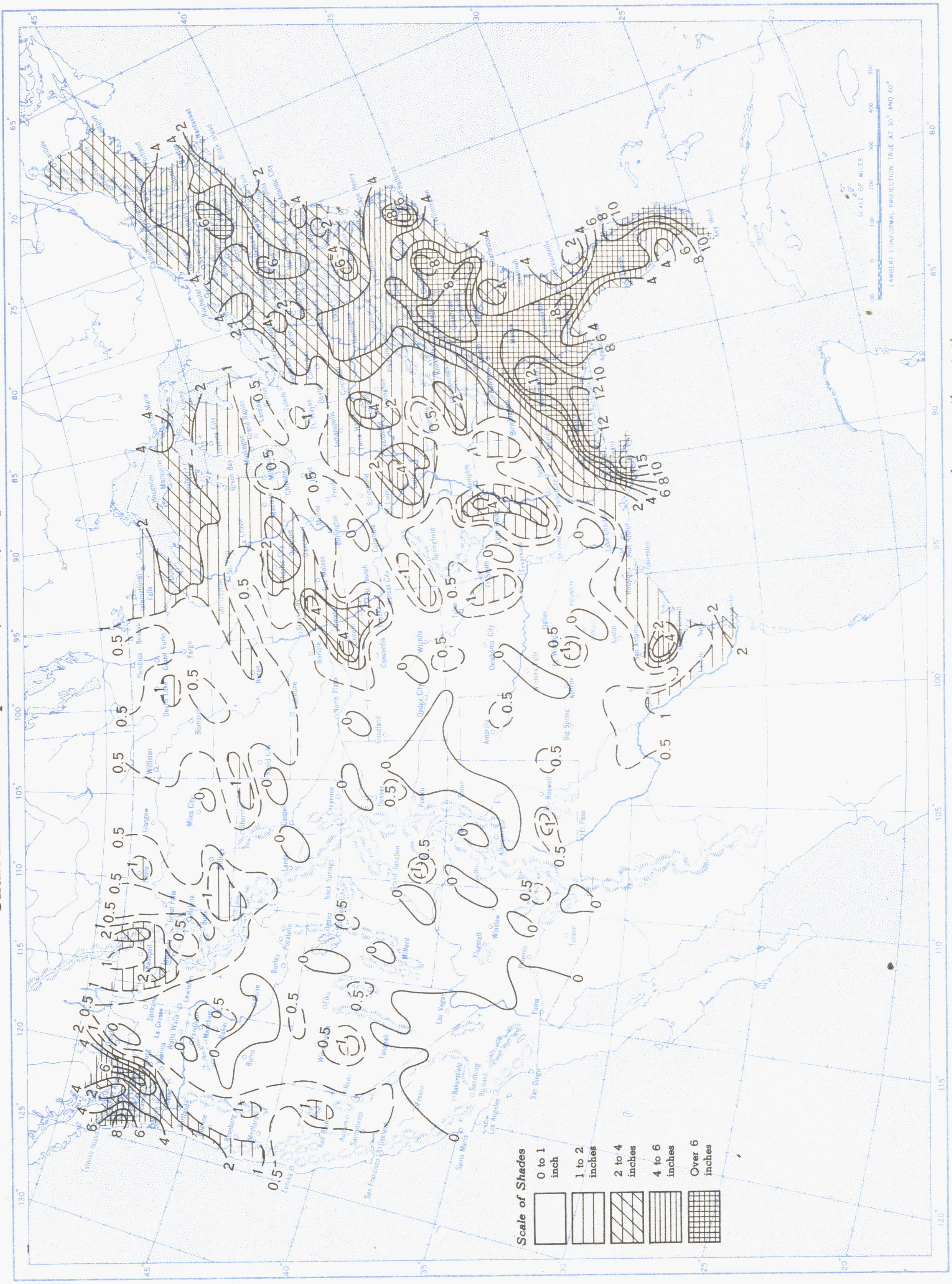
B. Departure of Average Temperature from Normal (°F.), September 1956.



A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.

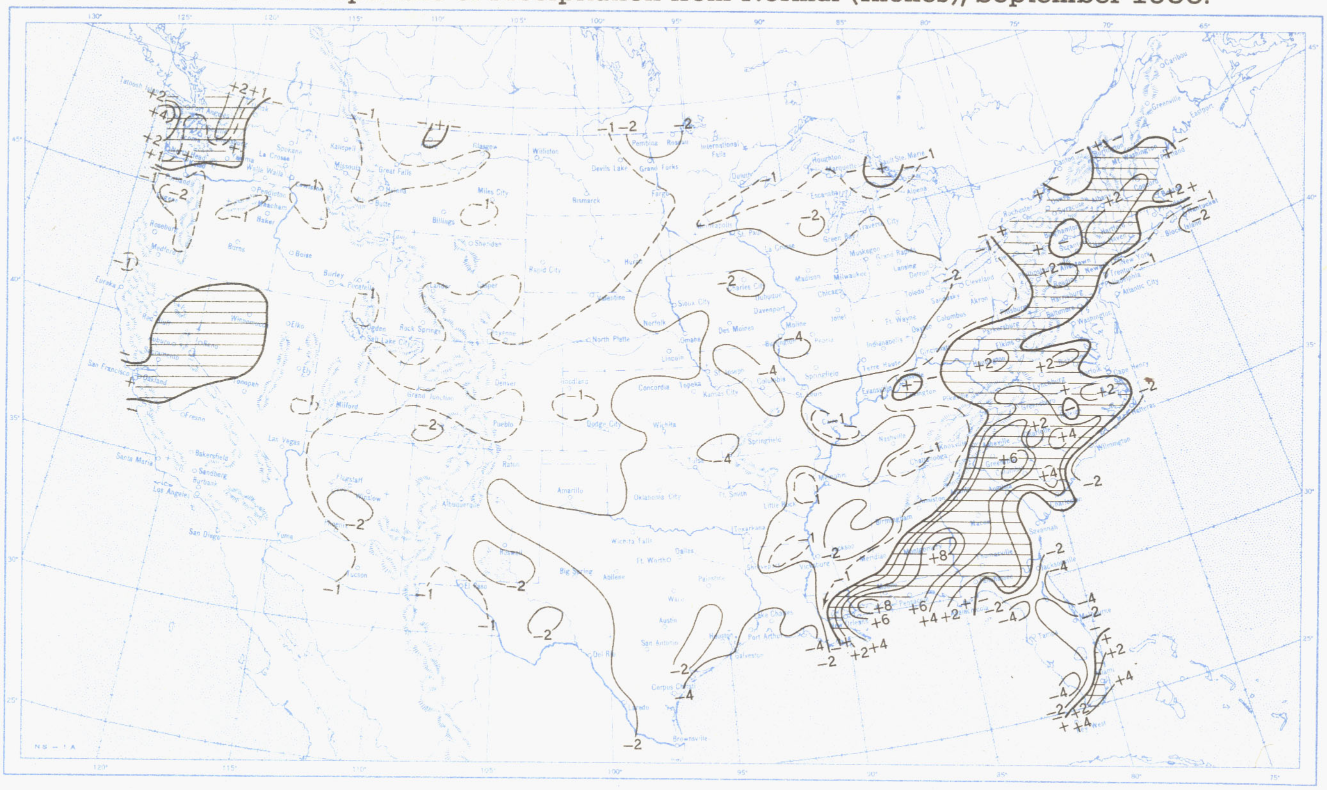
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), September 1956.

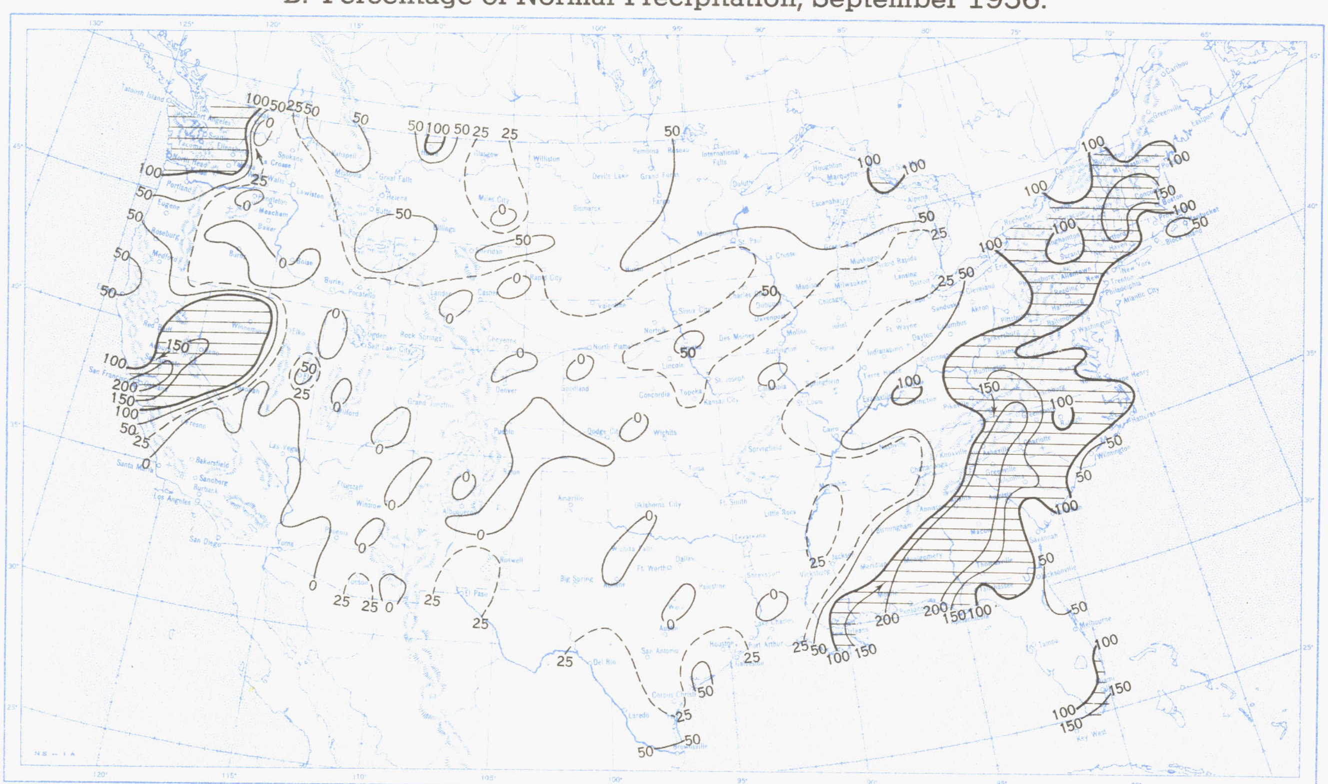


Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), September 1956.

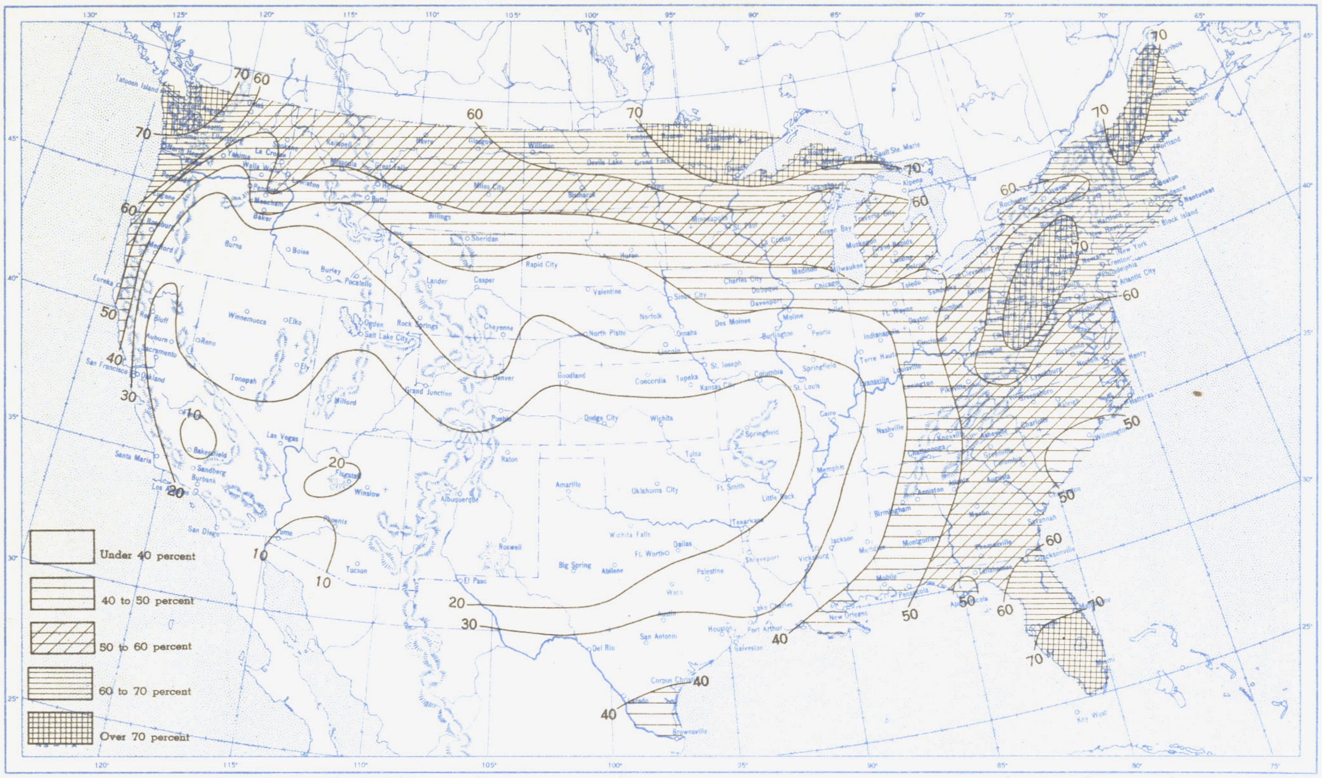


B. Percentage of Normal Precipitation, September 1956.

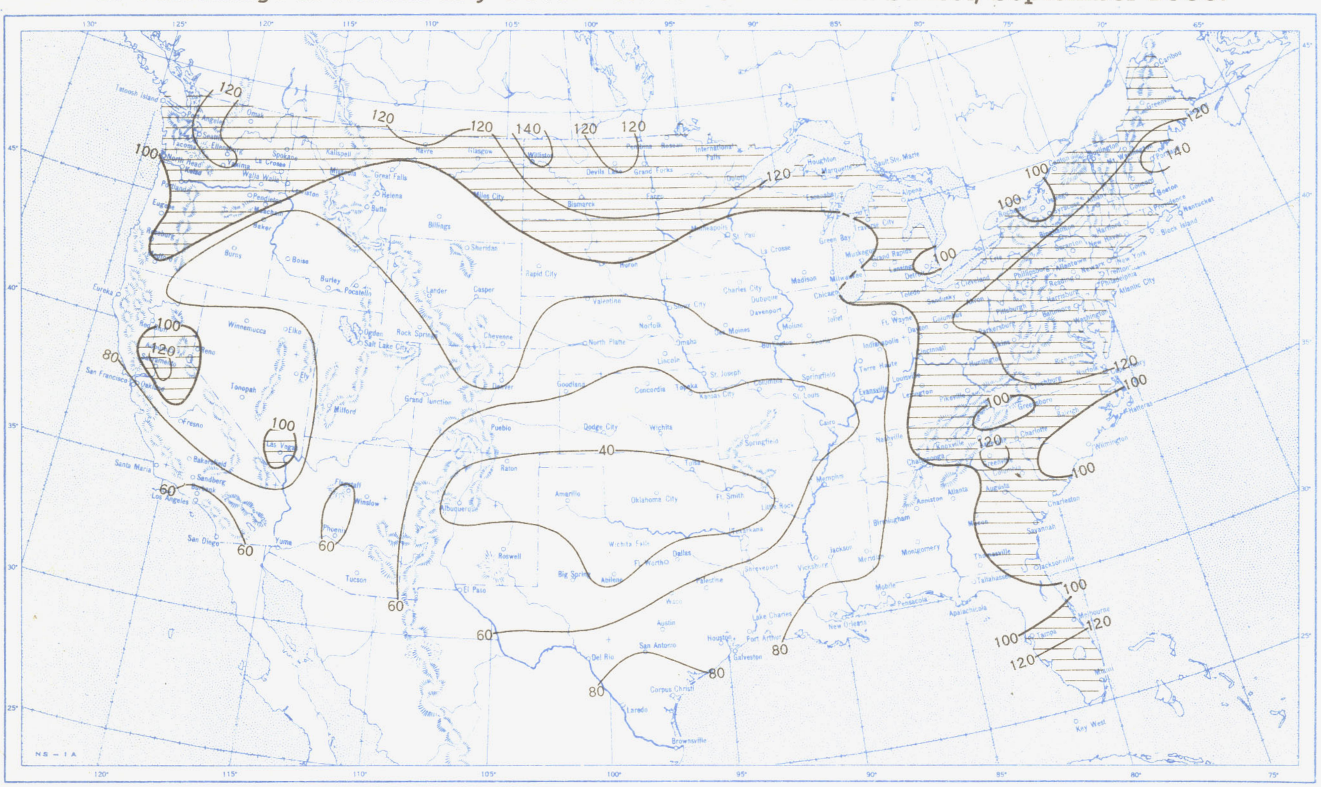


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, September 1956.

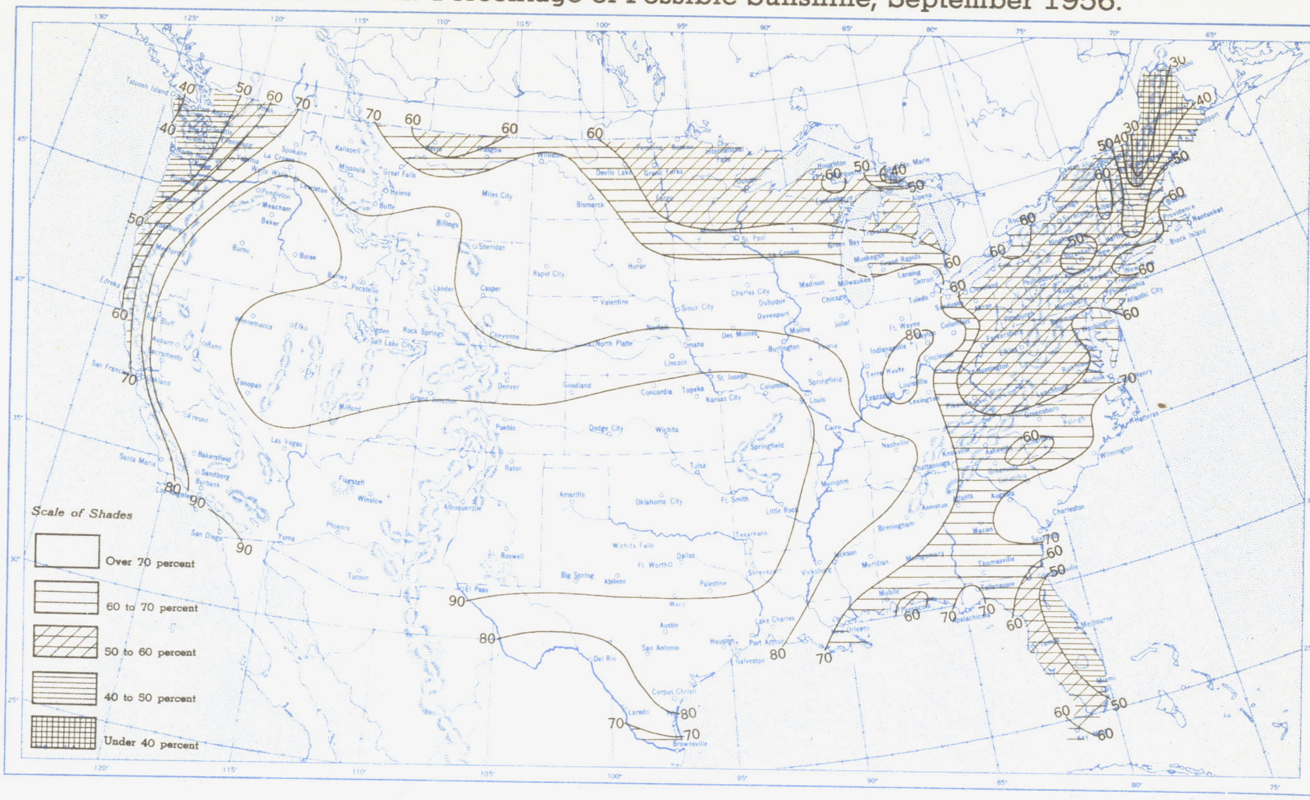


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, September 1956.

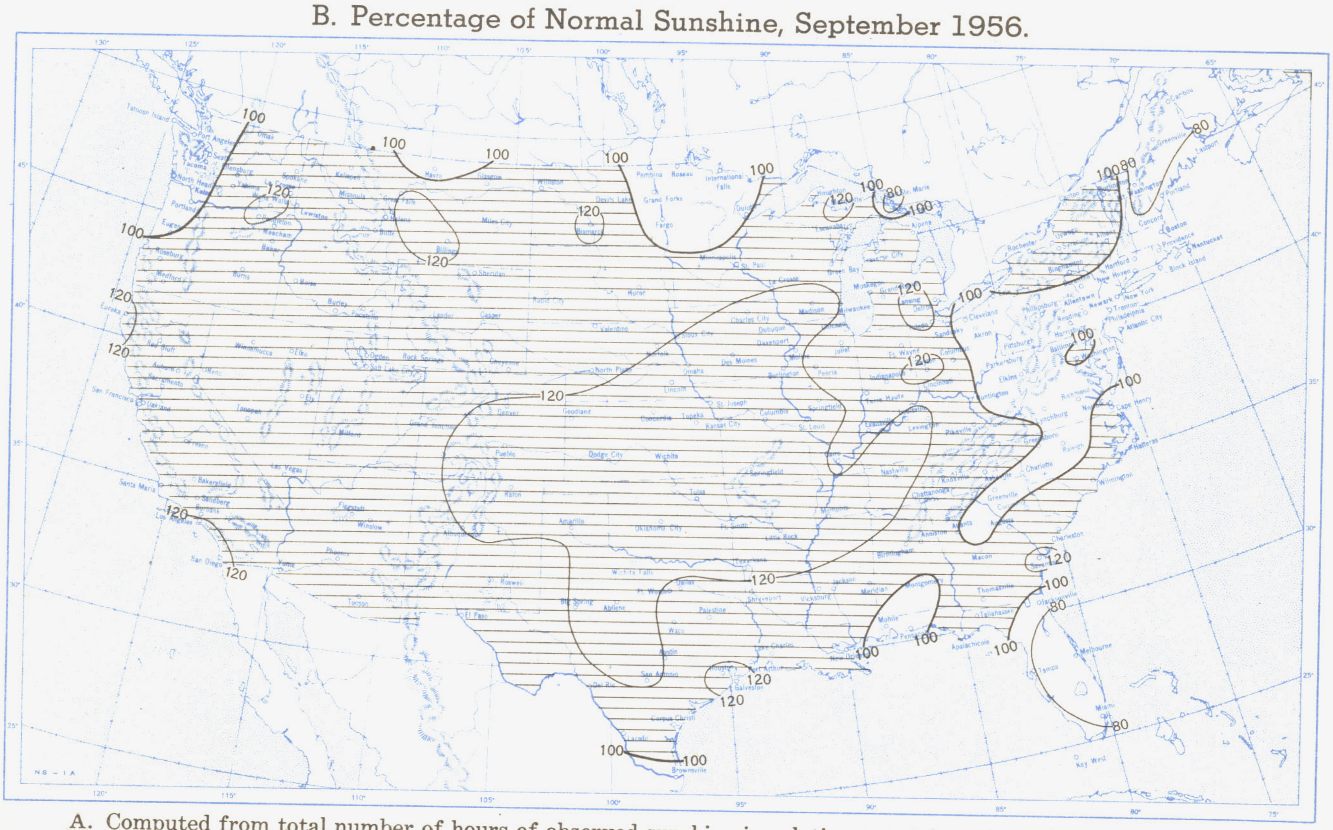


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, September 1956.



B. Percentage of Normal Sunshine, September 1956.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, September 1956. Inset: Percentage of Mean Daily Solar Radiation, September 1956. (Mean based on period 1951-55.)

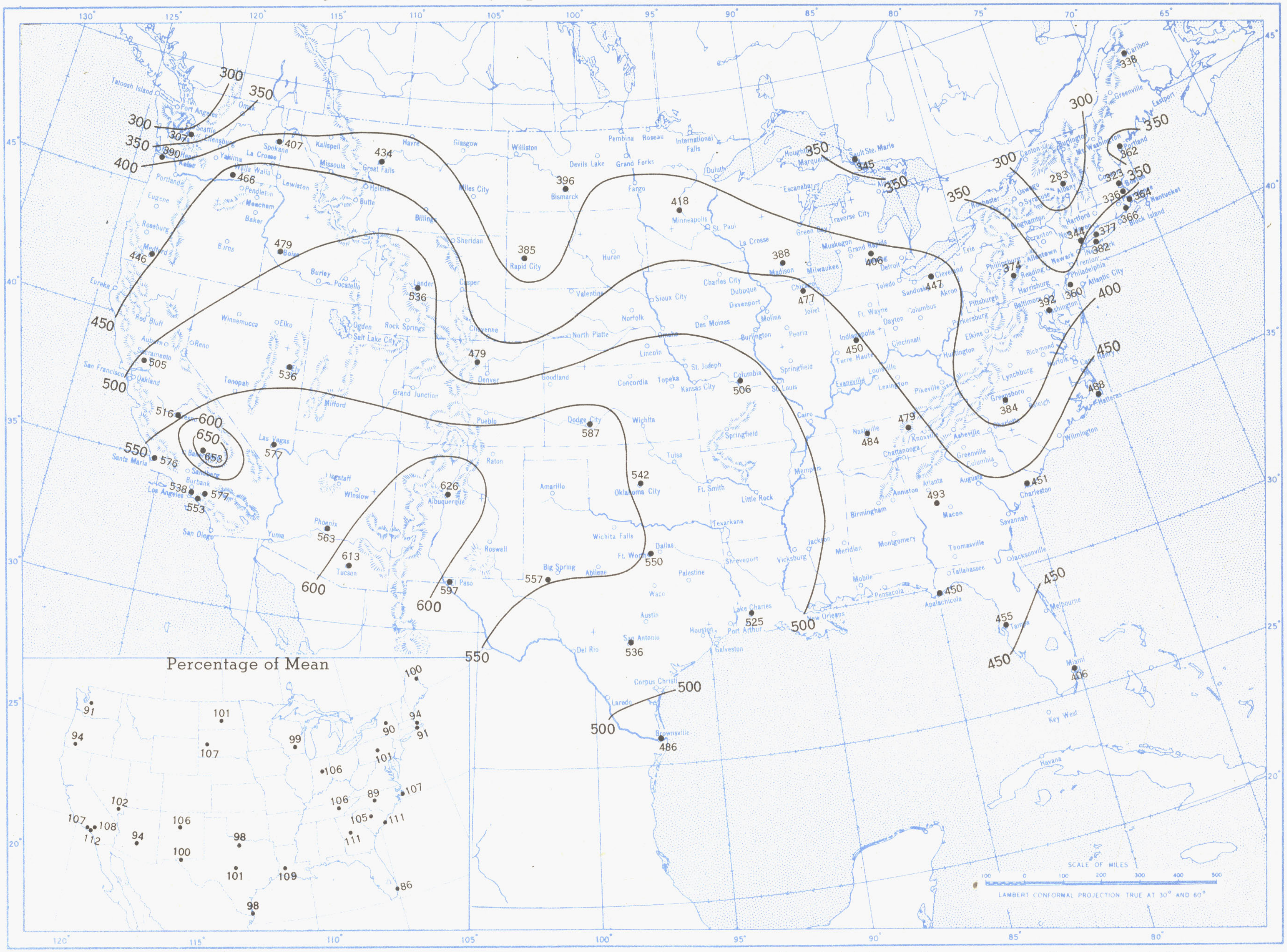
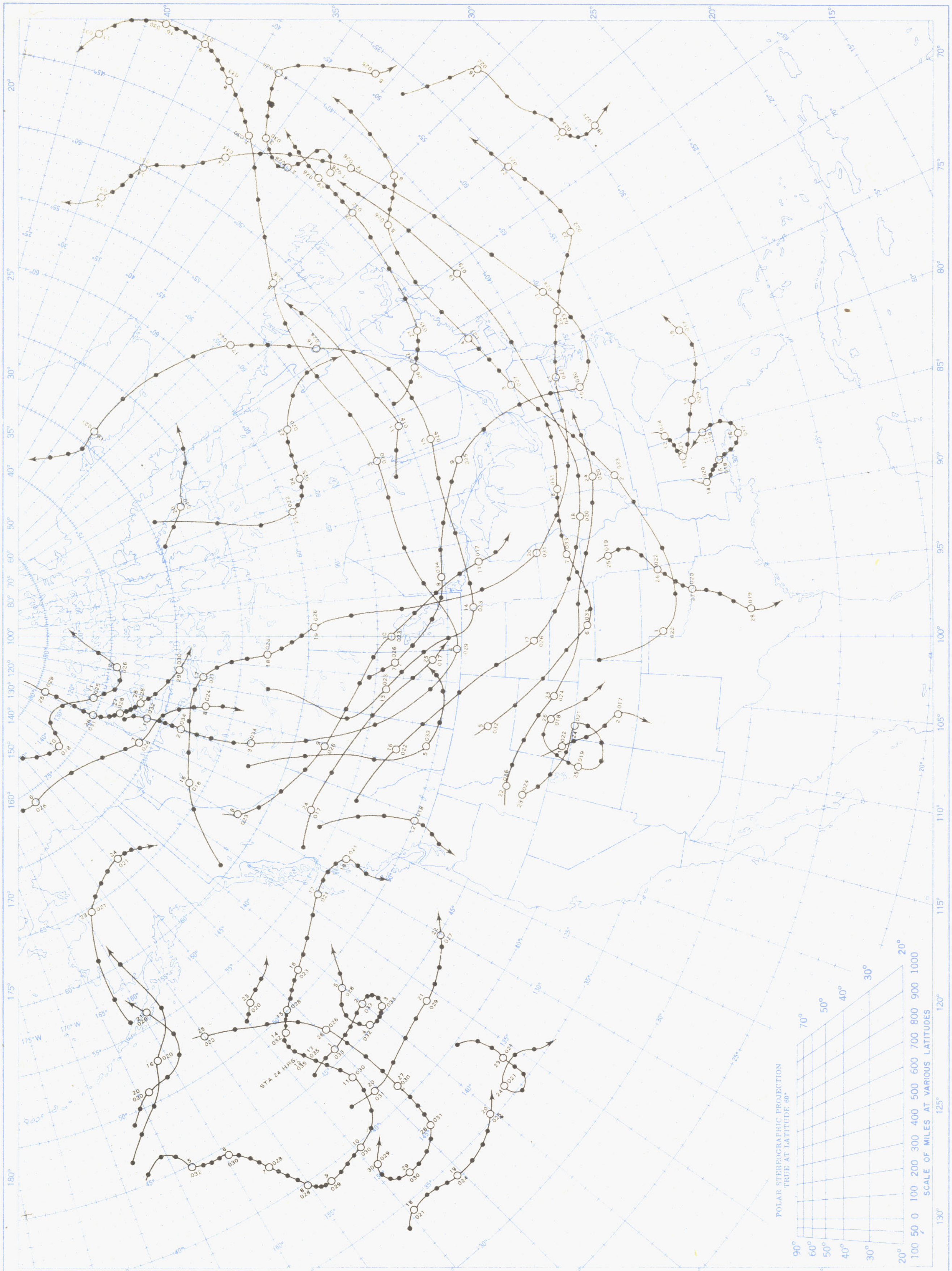


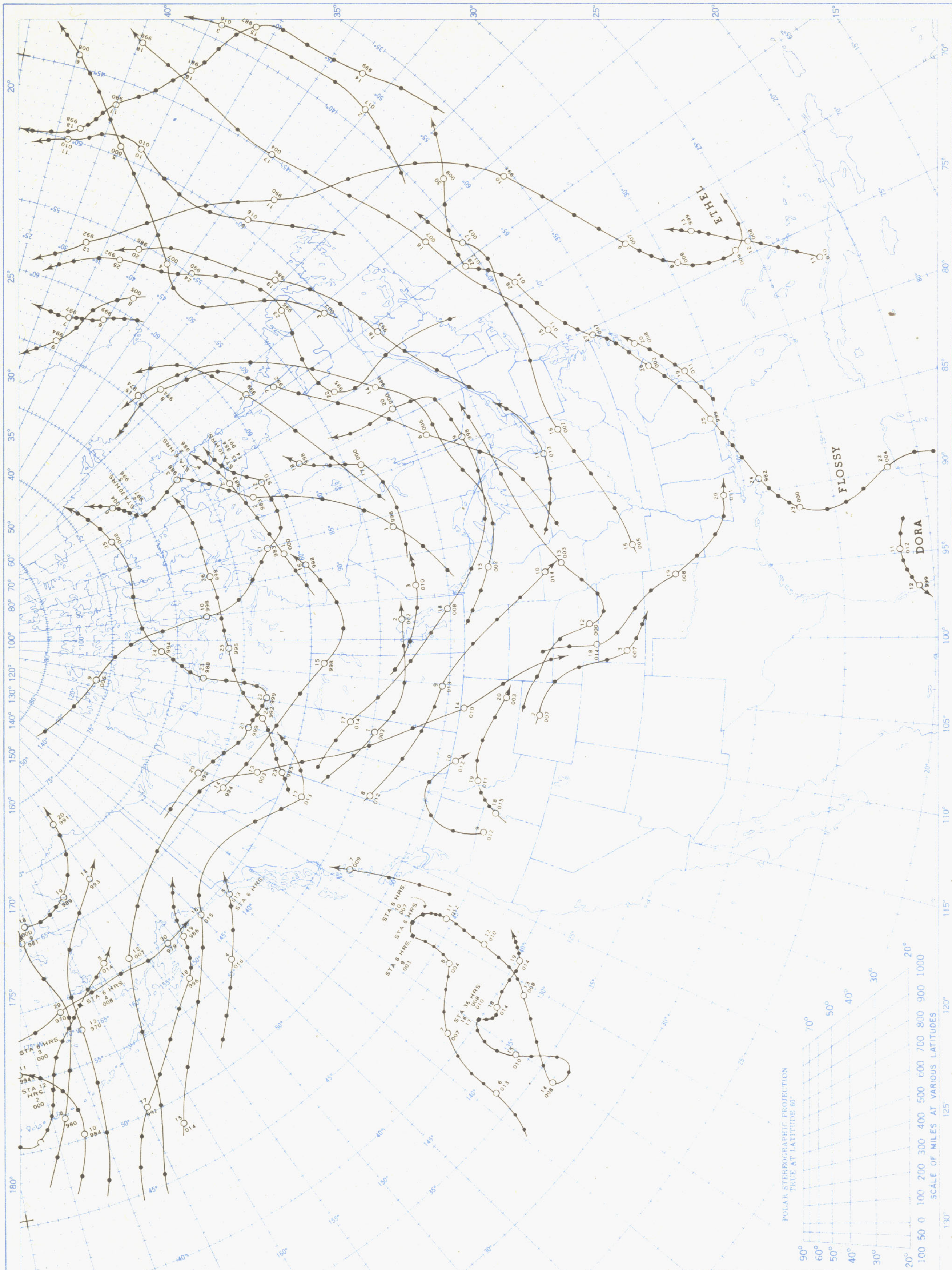
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, September 1956.



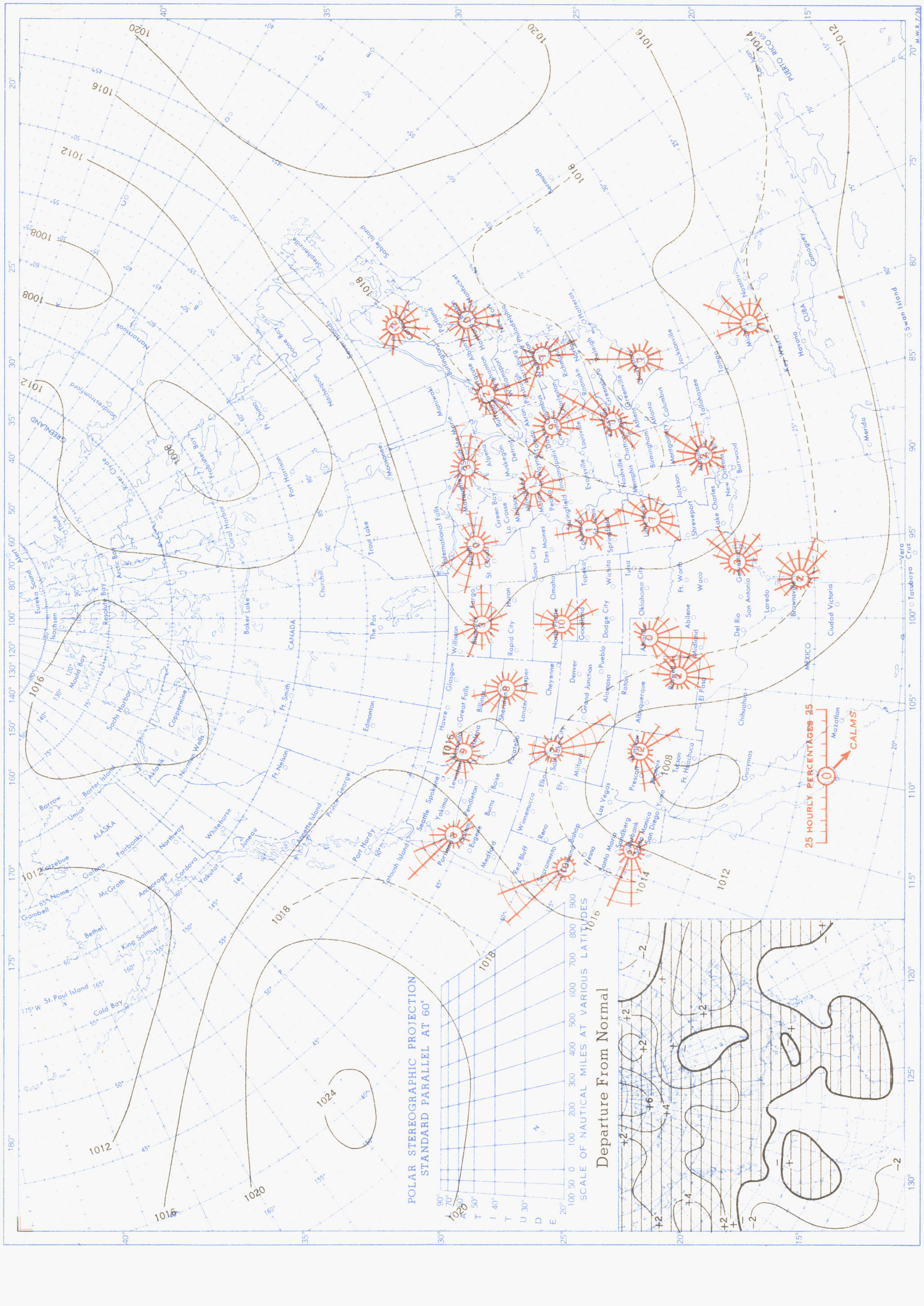
Circle indicates position of center at 7:30 a.m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, September 1956.



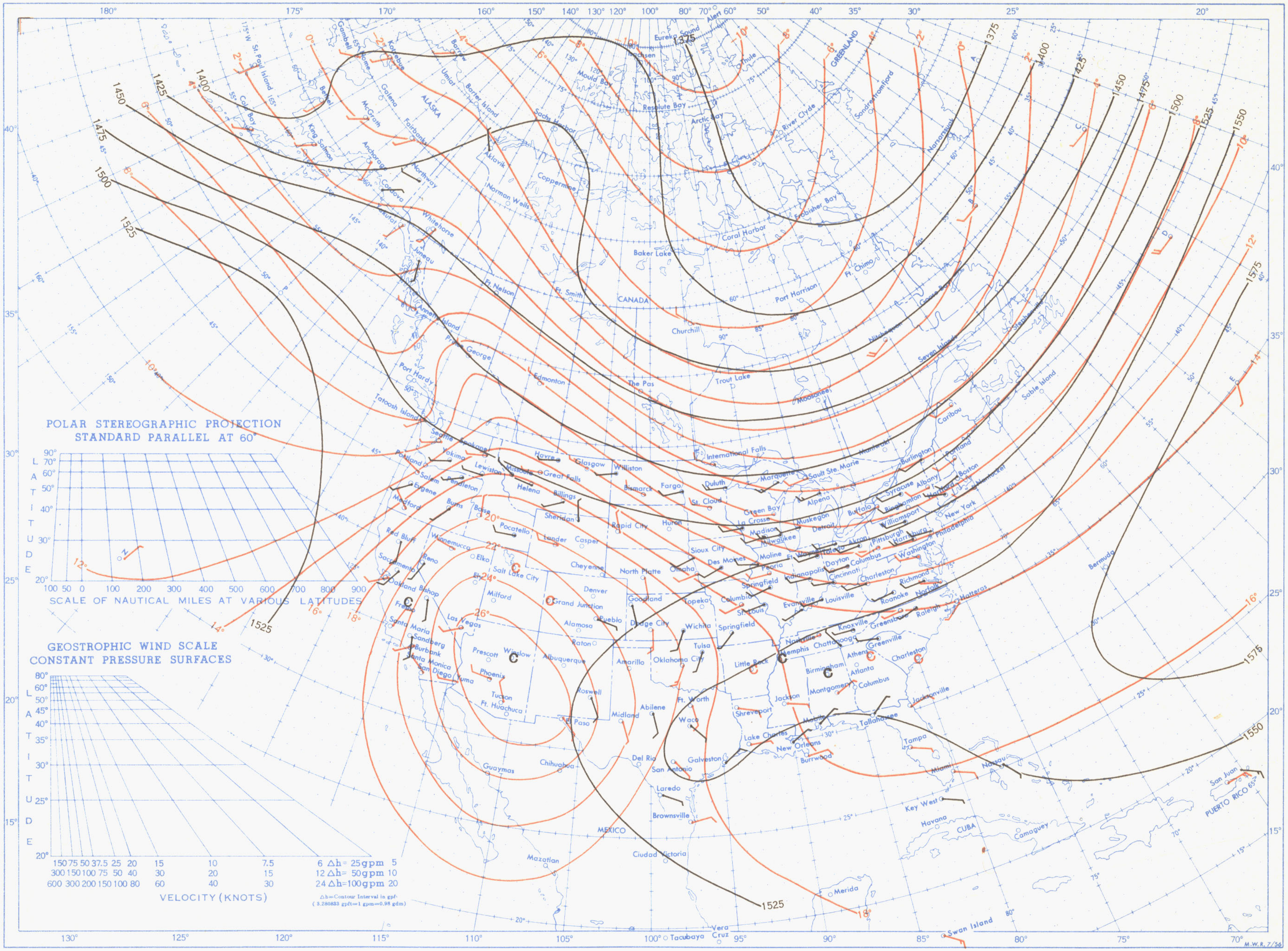
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, September 1956. Inset: Departure of Average Pressure (mb.) from Normal, September 1956.



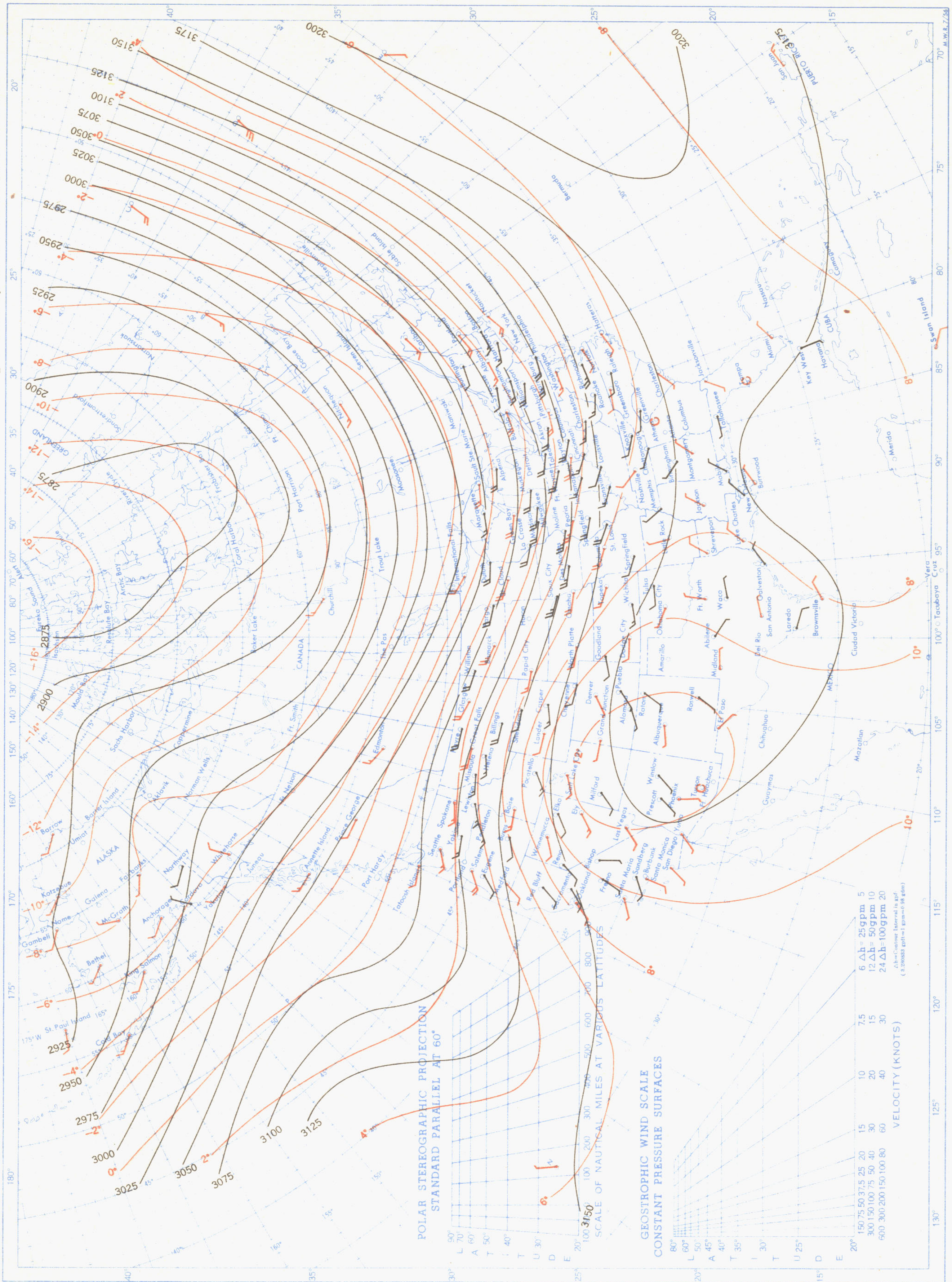
Average sea level pressures are obtained from the averages of the 7:30 a.m. and 7:30 p.m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. 850-mb. Surface, 0300 GMT, September 1956. Average Height and Temperature, and Resultant Winds.



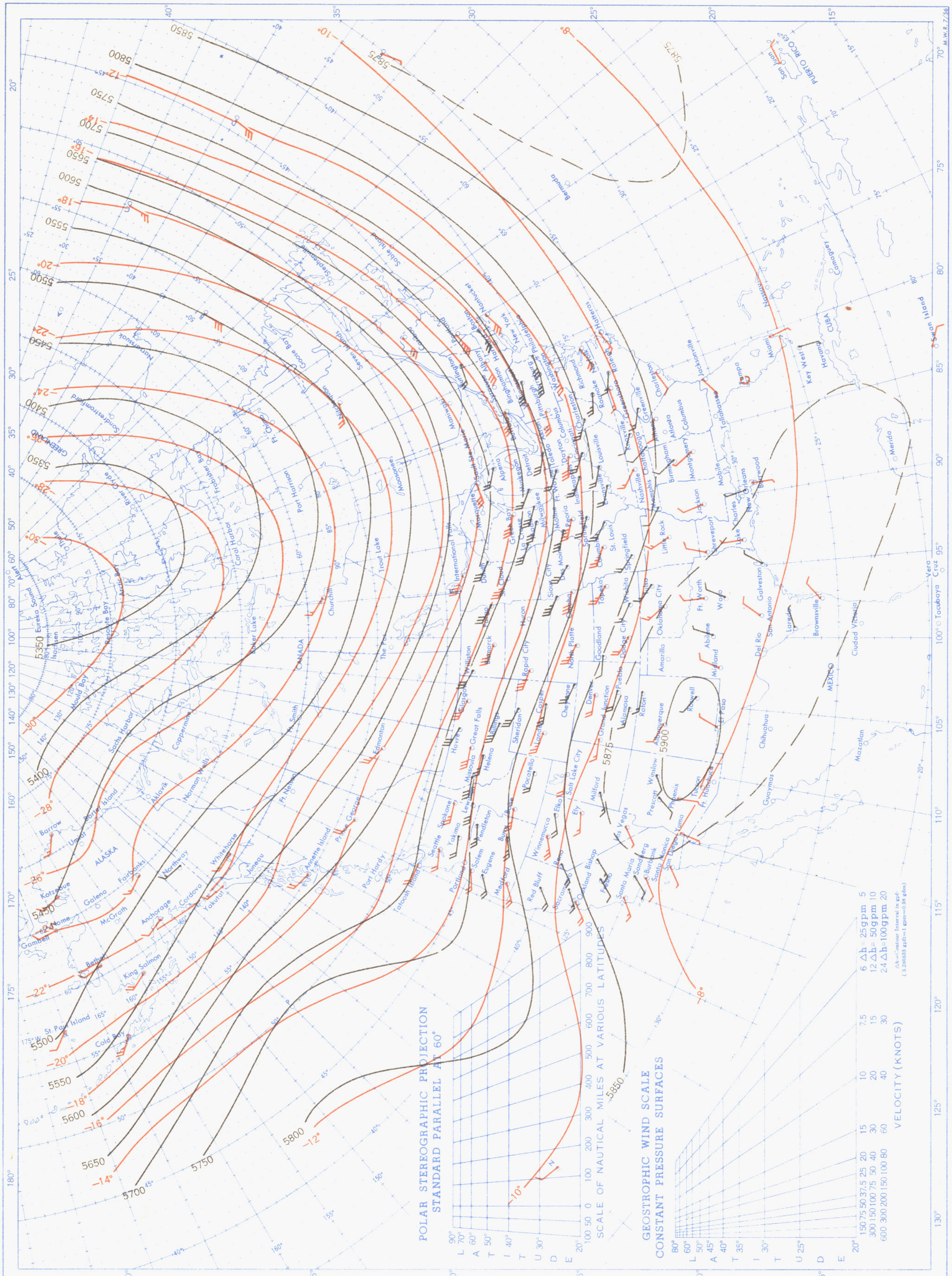
Height in geopotential meters (1 g.p.m. = 0.98 dynamic meters). Temperature in °C. Wind speed in knots; flag represents 50 knots, full feather 10 knots, and half feather 5 knots. Winds shown in red are based on rawins taken at the indicated pressure surface and time. Those in black are based on pibals taken at 2100 GMT and are for the nearest standard height level.

Chart XIII. 700-mb. Surface, 0300 GMT, September 1956. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map.

Chart XIV. 500-mb. Surface, 0300 GMT, September 1956. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map.

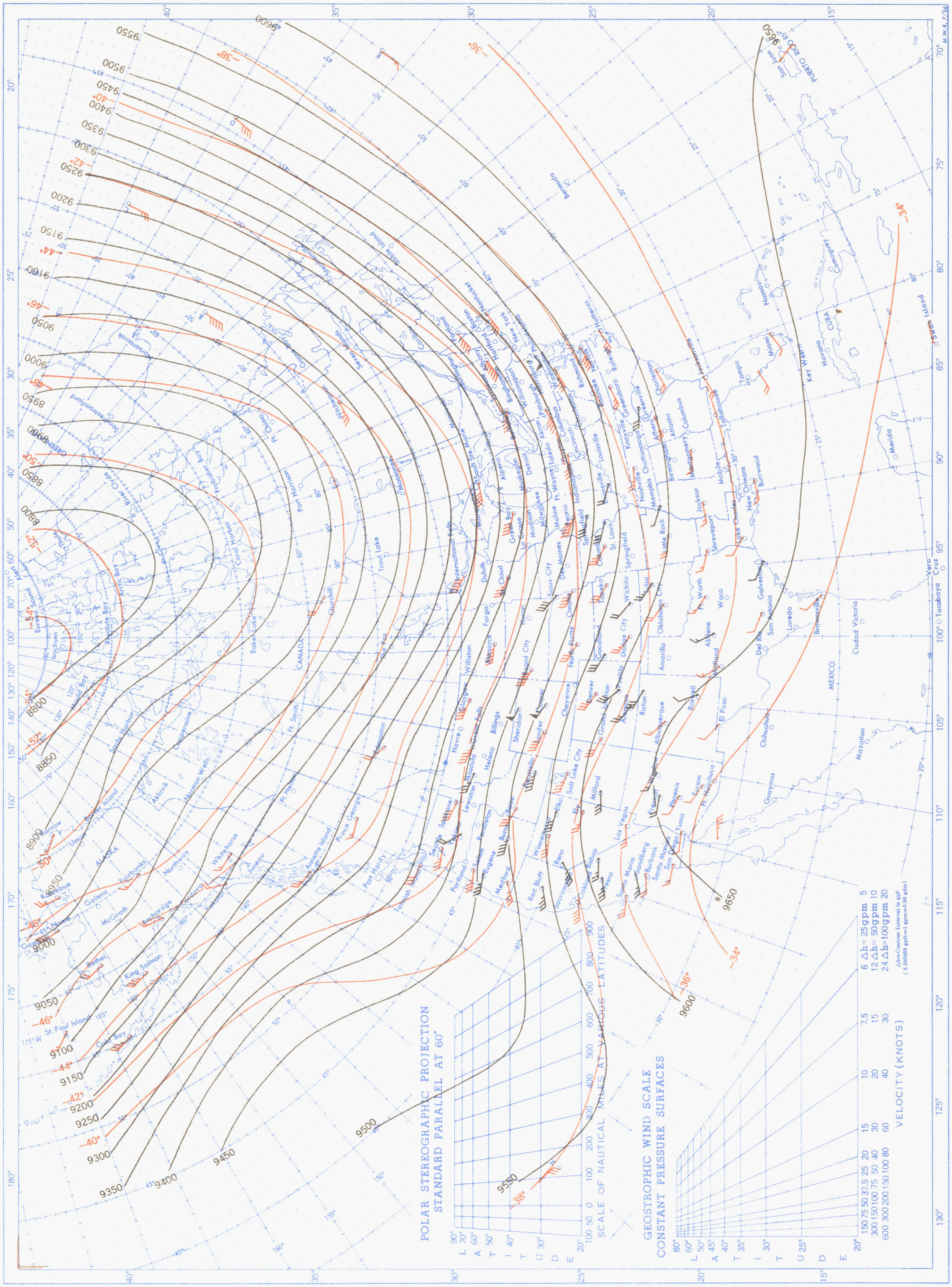
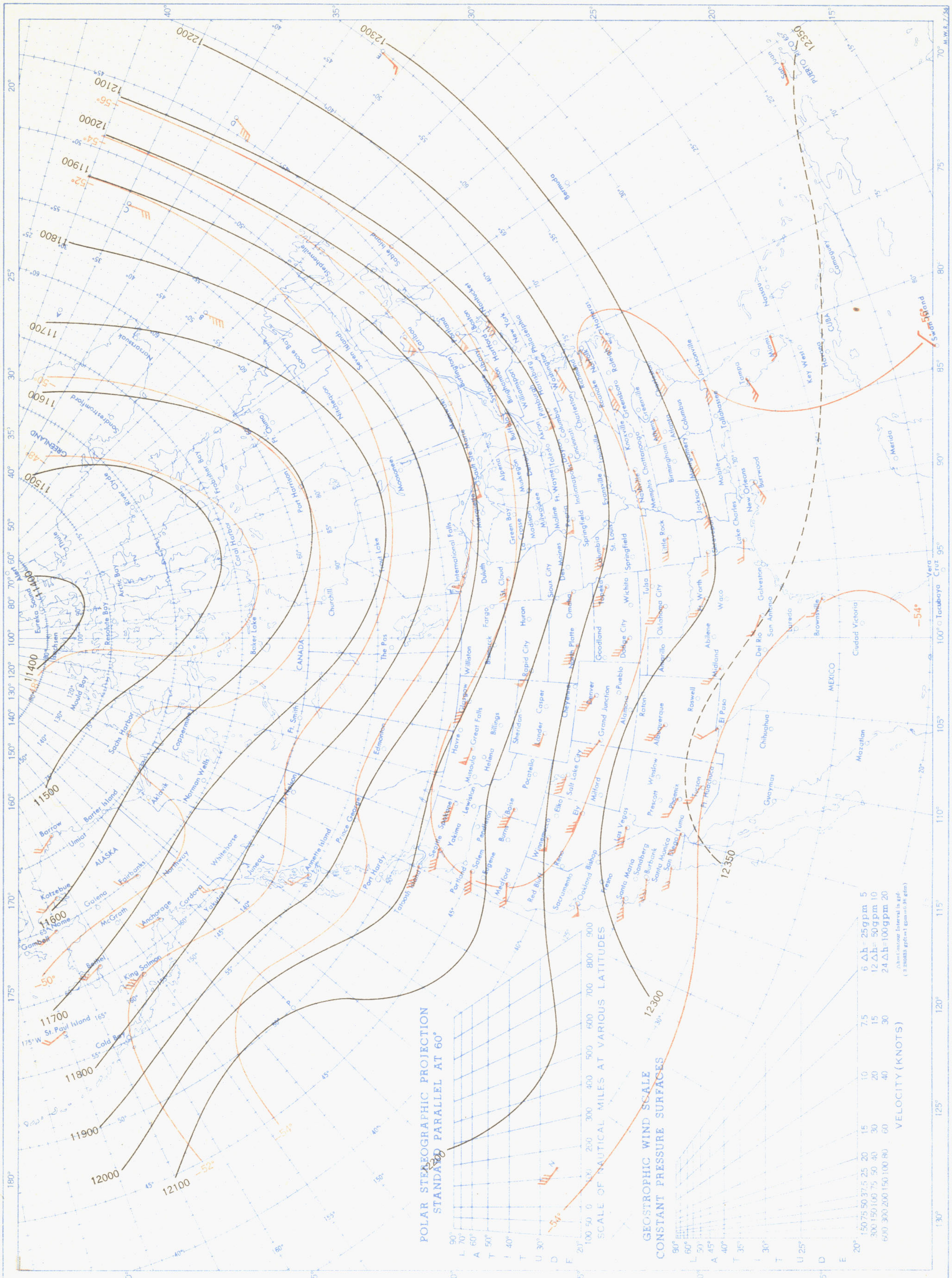


Chart XV. 300-mb. Surface, 0300 GMT, September 1956. Average Height and Temperature, and Resultant Winds.

See Chart XII for explanation of map.

Chart XVI. 200-mb. Surface, 0300 GMT, September 1956. Average Height and Temperature, and Resultant Winds.



See Chart XII for explanation of map. All winds are from rawin reports.

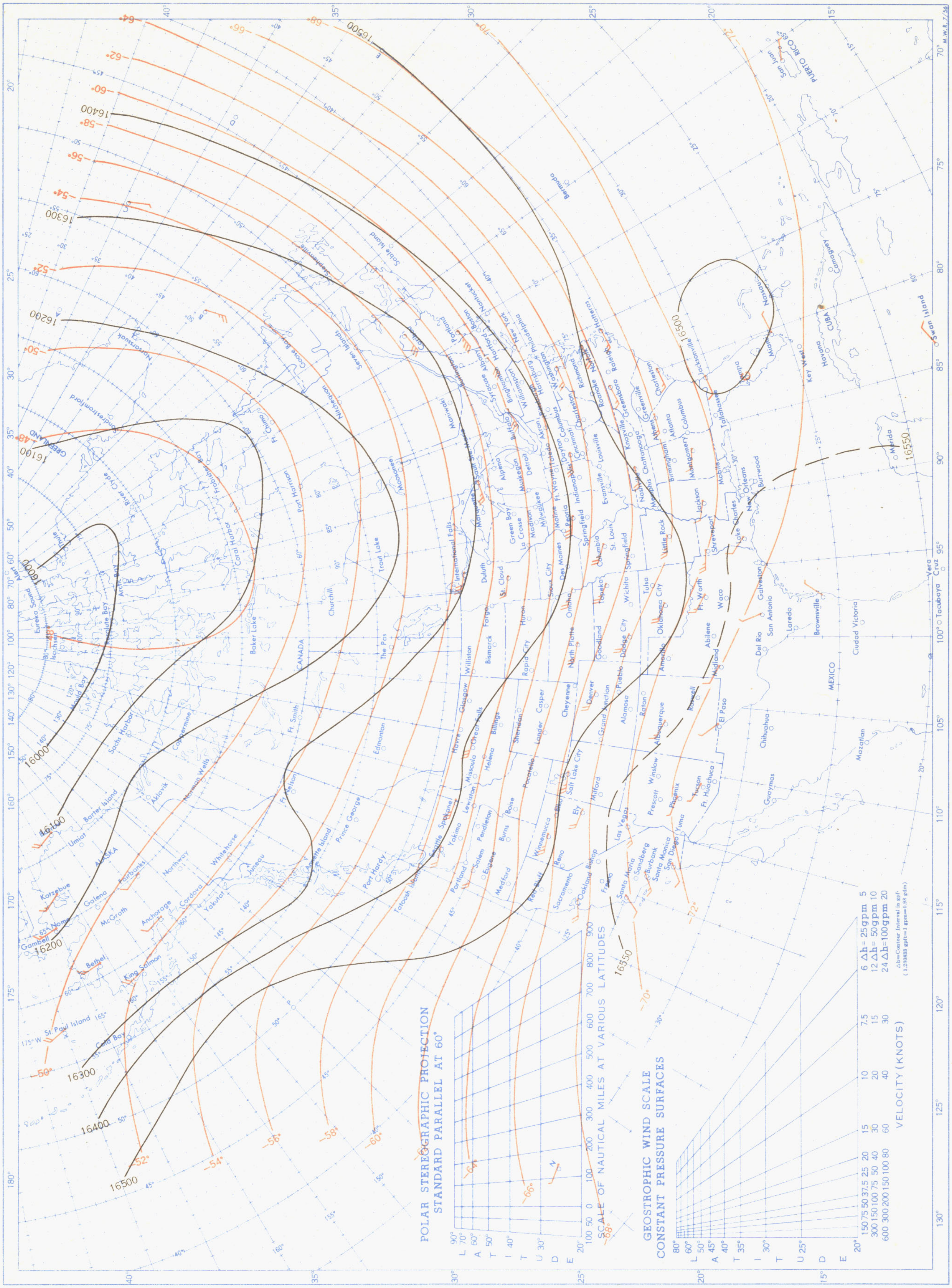


Chart XVII. 100-mb. Surface, 0300 GMT, September 1956. Average Height and Temperature, and Resultant Winds.

See Chart XII for explanation of map. All winds are from rawin reports.